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Experimental Investigation on Some Mechanical Properties of SFC Mixture

التحري التجريبي لبعض الخواص الميكانيكية للخرسانة المسلحة بأستخدام ألالياف الحديدية

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Abstract. With the increasing use of fiber reinforced concrete as a structural material, more information on its mechanical properties is needed. This paper express to characterize the stress-strain properties of fiber reinforced concrete mortar in compression. An experimental program was designed to show how the addition of steel fibers with 1.0 percent volume fractions affected the compressive strength, and compared with those with zero steel fiber. In general, the fibers pent the material and delayed the crack propagation, thus producing an increase the compressive

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strength with about 50%. Another mechanical properties investigated in this experimental work, is the effect of the steel fiber on the tensile strength. The addition of 1.0 percent volume fractions of steel fiber lead to the primary benefits which improve the tensile response after cracking and improve crack control, also showed that any addendum of steel fiber to concrete improves the tensile toughness of concrete. The addition of the steel fiber results in the increase of the tensile strength of concrete ranging from (58 -62%) for up to 1.0 percent by volume of fibers.

Keywords: Steel fiber, compressive strength, direct tension, concrete, mechanical properties.

الخلاصة: يتناول البحث الدراسة التجريبية لتأثير أضافة الالياف الحديدية لبعض الخواص الميكانيكية للخرسانة، حيث مع تزايد استخدام الخرسانة المقواة بالألياف الحديدية في مختلف التطبيقات الانشائية اصبح من المهم دراسة تأثير تلك الالياف على خواص الخرسانة الميكانيكية، يختص هذا البحث بدراسة التأثير الحاصل على تحمل الانضغاط للخرسانة من خلال برنامج تجريبي يتضمن إضافة الياف حديدية بنسبة 1% من حجم الخرسانة، حيث أظهرت النتائج التجريبية الى زيادة مقاومة الانضغاط للخرسانة لما تقوم به هذه الالياف من توفير تقوية لخرسانة وكانت نسبة الزيادة الحاصلة لمقاومة الانضغاط بحدور50%.تناول البحث دراسة سلوك الخرسانة تحت أحمال الشد بعد إضافة الالياف الحديدية، وكان ذلك من خلال برنامج تجريبي يتضمن فحص سلسلة من الأسطوانات الخرسانية المسلحة باستخدام الالياف الحديدية بنسبة 1% من حجم الخرسانة، حيث كان لوجود هذه الالياف التأثير بتحديد نمو و ازدياد التشققات الخرسانية من خلال زيادة مقاومة الخرسانة للشد بحدود نسبة (58 -62%)%.

1. INTRODUCTION

Concrete is a composite material containing hydraulic cement, water, coarse aggregate and fine aggregate. The resulting material is a stone like structure, which is formed by the chemical reaction of the cement and water. This stone such as material is a brittle material that is strong in compression but very weakly in tension. This weakness in the concrete makes it to crack under small loads, at the tensile end. These cracks gradually propagate to the compression end of the member and finally, the member breaks. The formation of cracks in the concrete may also occur due to the drying shrinkage. These cracks are micro cracks. These cracks increase in size and magnitude as the time elapses and the finally makes the concrete to fail [1].

The fashioning of cracks is the main reason for the failure of the concrete. To increase the tensile strength of concrete many attempts have been made. One of the succeeded and most commonly used method is providing steel reinforcement. Steel bars, however, reinforce concrete against

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local tension only. Cracks in reinforced concrete members provide freely until encountering are bar. Thus, need for multidirectional and closely spaced steel reinforcement arises. That cannot be practically possible. Fiber reinforcement gives the solution for this problem.

So to increase the tensile strength of concrete a technique of introduction of fibers in concrete is being used. These fibers act as crack arrestors and prevent the propagation of the cracks. These fibers are uniformly distributed and randomly arranged. This concrete is named as fiber reinforced concrete (FRC) [2].

The main reasons for adding fibers to concrete matrix is to improve the post- cracking response of the concrete, i.e., to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control. Also, it helps to maintain structural integrity and cohesiveness in the material. The initial researches combined with the large volume of follow up research have led to the development of a wide variety of material formulations that fit the definition of Fiber Reinforced Concrete [3].

2. FIBER REINFORCED CONCRETE (FRC):

Fiber reinforced concrete (FRC) is concrete containing fibrous material that increases its structural integrity. Therefore, we can define fiber reinforced concrete as a composite material of cement concrete or mortar and discontinuous discrete and uniformly dispersed fiber (Johnston, C. D., 2001).

Fiber is discrete material having some characteristic properties. The fiber material can be anything. But not all will be effective and economical. Some fibers that are most commonly used are [4,5]:

- Steel
- Glass
- Carbon
- Natural
- Non-Biodegradable (NBD)

Steel fiber is one of the most commonly used fiber. Generally round fibers are used. The diameter may vary from 0.25 to 0.75mm.The steel fiber sometimes gets rusted and lose its strength. But investigations have proved that fibers get rusted only at surfaces. It has high modulus of elasticity. Use of steel fibers makes significant improvements in flexure, impact and fatigue strength of concrete. It has been used in various types of structures.

Glass fiber is a recently introduced fiber in making fiber concrete. It has very high tensile strength of 1020 to 4080Mpa. Glass fiber concretes are mainly used in exterior building façade panels and as architectural precast concrete. This material is very good in making shapes on the front of any building and it is less dense than steel.

Use of carbon fiber is not a developed process. But it has considerable strength and young's modulus. Also investigations have shown that use of carbon makes the concrete very durable. The study on the carbon fibers is limited. Mainly used for cladding purpose.

Natural fibers are low cost and abundant. They are nonhazardous and renewable. Some of the

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natural fibers are bamboo, jute, coconut husk, elephant grass. They can be used in place of asbestos. It increases toughness and flexural strength. It also induces good durability in concrete.
Disposal of non-biodegradable materials is a serious problem. It creates environmental problems. Reusing is the best option to reduce the waste. These NBD materials are non corrosive, resistant to chemical attack, light in weight, easy to handle. NBD materials - fiber plastic, jute plastic, polythene, disposal glass, cement bags.
Studies conducted so far, proved that the short and discrete, small fibers can improve the flexural load carrying capacities and impact resistance for nonferrous fibers.

3. HISTORY:

The use of fibers to increase the structural properties of construction material is not a new process. From ancient times, fibers were being used in construction. In BC, horsehair was used to reinforce mortar. Egyptians used straw in mud bricks to provide additional strength. Asbestos was used in the concrete in the early 19th century, to protect it from formation of racks. But in the late 19th century, due to increased structural importance, introduction of steel reinforcement in concrete was made, by which the concept of fiber reinforced concrete was over looked for 5-6 decades [6,7]. Later in 1939, the introduction steel replacing asbestos was made for the first time. However, at that period it was not successful. From 1960, there was a tremendous development in the FRC, mainly by the introduction of steel fibers. Since then use of different types of fibers in concrete was made [8]. In 1970's principles were developed on the working of the fiber reinforced concrete. Later in 1980's certified process was developed for the use of FRC. In the last decades, codes regarding the FRC are being developed [7].

4. PROPERTIES OF FIBER REINFORCED CONCRETE:

Properties of concrete is affected by many factors like properties of cement, fine aggregate, coarse aggregate. Other than this, the fiber reinforced concrete is affected by following factors:

- Type of fiber
- Aspect ratio
- Quantity of fiber
- Orientation of fiber

Type of fiber:

A good fiber is the one, which possess the following qualities:

- Good adhesion within the matrix.
- adaptable elasticity modulus (sometimes higher than that of the matrix)
- compatibility with the binder, which should not be attacked or destroyed in the long term
- an accessible price, taking into account the proportion within the mix
- being sufficiently short, fine and flexible to permit mixing, transporting and placing
- Being sufficiently strong, yet adequately robust to withstand the mixing process.

Aspect ratio:

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Aspect ratio is defined as the ratio of length to width of the fiber. The value of aspect ratio varies from 30 to 150. Generally the increase in aspect ratio increases the strength and toughness till the aspect ratio of 100. Above that the strength of concrete decreases, in view of decreased workability and reduced compaction. From investigations, it can be found out that good results are obtained at an aspect ratio around 80 for steel fibers.

Fiber quantity:

Generally quantity of fibers is measured as percentage of cement content. As the volume of fibers increase, there should be increase in strength and toughness of concrete. Regarding our fiber, we hope that there will be an increase in strength, with increase in fiber content. We are going to test for percentages of 1.0.

Orientation of fiber:

The orientations of fibers play a key role in determining the capacity of concrete. In RCC the reinforcements are placed in desired direction. But in FRC, the fibers will be oriented in random direction. The FRC will have maximum resistance when fibers are oriented parallel to the load applied.

5. FIBER MECHANISM:

Fiber work with concrete utilizing two mechanisms: the spacing mechanism and the crack bridging mechanism. The spacing mechanism requires a large number of fibers well distributed within the concrete matrix to arrest any existing micro crack that could potentially expand create a sound crack. For typical volume of fractions of fibers, utilizing small diameter of fibers or micro fibers can ensure the required no of fibers for micro crack arrest.

The second mechanism termed crack bridging requires larger straight fibers with adequate bond to concrete. Steel fibers are considered a prime example of this fiber type that is commonly referred as large diameter fibers or micro fibers [9].

6. EXPERIMENTAL PROGRAM

6.1 Composition of steel fiber reinforced concrete

The present experimental program components of Steel Fiber Reinforced Concrete (SFRC) can be explained with the **.**

Concrete containing hydraulic cement, water, fine aggregate, coarse aggregate and discontinuous discrete Steel fibers is called Steel Fiber Reinforced Concrete. It may also contain pozzolans and other admixtures commonly used with conventional concrete. Fibers of various shapes and sizes produced from steel, plastic, glass and natural materials are being used. However, for most structural and non-structural purposes, steel fiber is commonly used of all the fibers.

6.1.1 Steel fiber

This research focuses on steel fibers. Uploaded type of steel fibers hooked end (cold drawn wire) classes of steel fiber defined by (ASTM A 820), as shown in Fig. 2,with the following specifications listed in Table 1.

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Table 1. Steel fiber specifications

L[mm]	D [mm]	L/D	fy [N/mm]	No/kg	Young's Modulus (GPa)	Density kg/m^3
30	0.55	54.55	1500	16750	200	7850

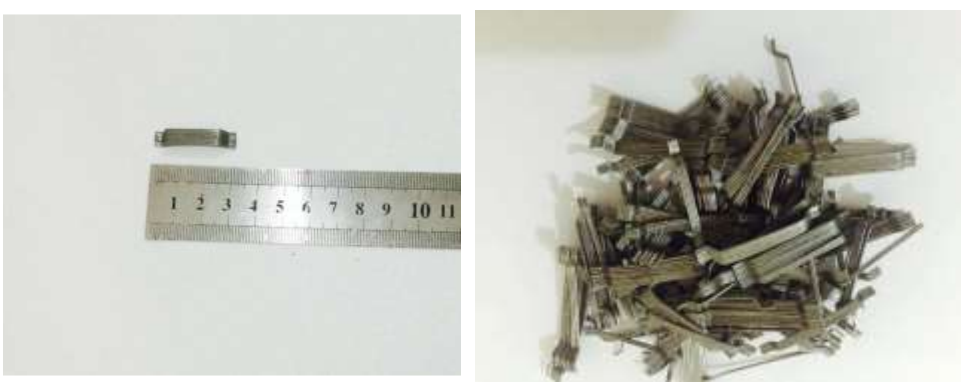

Fig. 1, Steel fiber used in the present work

6.1.2 Concrete

Cement: The cement type used is Portland cement type (CEM ll / A-LL 42.5 R). Shown in Fig. 3, with the physical propertied presented in Table 2. The chemical compositions is presented in Table. 3.

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Fig. 2, Portland cement used in the present work

Table 2. Physical and mechanical properties of Portland cement

Compressive Strength 28 day (MPa)	Initial Setting time (min)	Soundness Expansion (mm)
Minimum (42.5) Maximum m (62.5)	≥60	≤10

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Table 3 Chemical compositions of portland cement

Analysis Report (%)	Cement
CaO	63.79
SiO_2	20.03
Al_2O_3	4.03
Fe_2O_3	2.59
MgO	2.96
SO_3	2.76
K_2O	0.71
Na_2O	0.10
MnO	2.06
Ignition loss	6.13
Specific surface area (m^2/kg)	326
Specific gravity	3.15

Coarse and fine aggregate: Crushed stone with a maximum size of 4 mm was used in this experiment as course aggregate and fine aggregate, which is natural river sand maximum size of 0.5 mm was utilized in this research. Shown in Fig. 4 and Table 4.

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Fig3 Coarse and fine aggregates used in the present study.

Table 4 Sieve analysis of fine and course aggregates

Sieve Size (mm)	Crushed stone (16-8) mm	Crushed stone (8-4) mm	Natural River sand (0.5) mm
0.25	0	0	3.79
0.5	0	0	14.27
1	0	0	30.85
2	0	0	49.35
4	0	2.05	83.06
8	1.28	66.66	100
16	78.19	100	100
Specific gravity	2.66	2.65	2.58

Silica fume: In Current search, Silica fume, Fig. 5, was used as additional cementitious material. Specific gravity and specific surface area of the silica fume were 2.2 and 21.80 m2/kg, respectively. Table 5 presents the silica fume properties.

Table 5 Properties of silica fume

Constituent (%)	Silica Fume
Ca O	0.45
SiO	90.36
Al2O3	0.71
FeO3	1.31
SO3	0.41
K2O	1.52
Na2O	0.45

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Loss of Ignition	3.11
Specific Surface	21. 80
Specific Gravity	2.2

Fig.4 Silica fume used in the present study.

Water: The tap water has been used for both mixing and curing of concrete.

Mineral Admixture: Master Glenium® 51 is a poly carboxylic ether based, high range water reducing new second-generation super plasticizer concrete admixture developed for ready mix concrete and precast industry that needs high early and final strengths and durability. Consistent with the TS EN 934-2 High range water reducing/Super plasticizer Concrete Admixture and ASTM C 494 Type F. The specific gravity of 1.07 was utilized every concrete mixes. The detailed characteristics of used High Range Water Reducing Admixture (HRWRA). Table 6 and Fig.6 .

Table 6 High range water reducing admixture (HRWRA)

Properties	HRWRA
Name	Glenium 51
Color	Dark brown
Condition	Liquid
Specific gravity (kg/l)	1.07
Chemical description	Modified polycarboxylic ploymer
Recommended dosage	1-2% (% binder content)

Fig.5 admixture used in the present study.

6.1.3 Mix design

The mix design used in the present study is presented in Table 7.

Table 7 Mix design for the present concrete mixture.

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mix code	Steel fiber	cement [kg]	gravel [kg]	sand [kg]	silica foam	HWR [kg]	water [Lt]
N	0.0%	465	680	1170	3.5	6.6	216
S1	1%	465	630	1170	3.5	6.6	216

Concrete Mixer: Mixer machine are used according to a certain speed for the period for mixing process. Fig. 7 shows the mix machine

Fig.6 Mixer machine for the present study

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7. Compressive strength of SFRC

The effect of steel fiber on the compressive strength of concrete has been discussed in many studies, and resulted that, the presence of the SF has slightly affect the compressive strength of concrete, but overall effect is negligible in many cases. Many researchers [10,11] have observed increases in the compressive strength of concrete ranging from (0 -15%) for up to 1.5 percent by volume of fibers. while other researchers observed that, the increase in the compressive strength range from negligible in most cases to 23 % for SFRC for up to 2.0 percent by volume of fiber [12].

The key role of steel fibers is to reduce the rate of strength loss after the peak stress. Several researchers [13, 14,15] study experimentally the compressive stress-strain behavior of SFRC mixture. One can observe from these compressive stress-strain relationships for SFRC that, a substantial increase in the strain at the peak stress and the modified unloading branch (i.e., less steep descending branch than that of normal concrete without SF).

That means the addition of steel fiber improve the toughness of SFC in compression, where toughness is a measure of ability to absorb energy during deformation, and it can be obtained from and this incensement in toughness is useful in preventing sudden failure under static loading.

The present experimental program consists of a series of compressive tests performed on (150 x 300 mm) cylindrical specimens of steel fiber concrete. The specimens were capped with a high-strength sulfur compound before testing. A typical specimen is illustrated in Fig.8 The present tests are part of a larger experimental program.

The focus of this paper is on those specimens that were reinforced only with steel fibers. Four specimens from each batch were tested under monotonic compressive loading, at a static strain rate. . Based on the results of these monotonic tests, shown in Table 8, one can observe that the increases in the compressive strength of concrete ranging from (48 -61%) for up to 1.0 percent by volume of fibers.

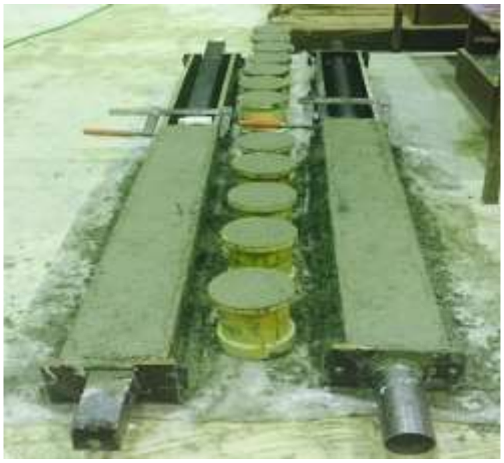

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Fig. 7 Cylinders of FRC for the present experimental work

Table 8 Experimental test results for FRC compressive strength

Spec. code	V_f (%)	Temp. (°C)	date		age (day)	Load (kN)	f'_c (MPa)	avg. fc (MPa)
			casted	tasted				
HN1		20	11/23/2016	2/10/2017	79	400.3	50.97	
HN2	0	20	11/23/2016	2/10/2017	79	366.8	46.70	50.10
HN3		20	11/23/2016	2/10/2017	79	413.5	52.65	
HS1	1	20	11/23/2016	2/10/2017	79	598.9	76.25	
HS2	1	20	11/23/2016	2/10/2017	79	612.5	77.95	76.8
HS3	1	20	11/23/2016	2/10/2017	79	598	76.2	

8. Tensile strength of SFRC

Plain concrete lose their tensile load-carrying capacity almost immediately after formation of the first crack. The addition of steel fiber to concrete mix result in significant improvement in strength of SFRC in direct tension, with increases of about (30-40%) for the addition of 1-1.5% by volume of steel fibers in concrete mix [16] . The toughness of SFRC in tension has been improved due to addition of SF and it will be one to two orders of magnitude higher, primarily because of the large frictional and fiber bending energy developed during fiber pullout on either side of a crack, and because of deformation at multiple cracks when they occur [17]. While the tensile strength beyond the first carking are not improved. Thus, SFRC is considered a quasi-brittle material with tension softening.

The present experimental program consists of a series of tensile tests performed on (150 x 300 mm) cylindrical specimens of steel fiber concrete. The focus of this paper is on those specimens that were reinforced only with steel fibers. three specimens from each batch were tested under monotonic compressive loading . Based on the results of the present tensile tests, shown in Table 9. One can observe that the increases in the tensile strength of concrete ranging from (58 -62%) for up to 1.0 percent by volume of fibers.

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Table 9 Experimental test results for FRC tensile strength

Spec. code	V_f (%)	Temp. (°C)	date		age (day)	Load (kN)	f_{ct} (Mpa)	avg. fct (Mpa)
			casted	tasted				
HN1	0	20	11/23/2016	2/10/2017	79	213.5	6.80	7.06
HN2		20	11/23/2016	2/10/2017	79	217.5	6.93	
HN3		20	11/23/2016	2/10/2017	79	230	7.32	
HS1	1	20	11/23/2016	2/10/2017	79	368	11.71	11.48
HS2		20	11/23/2016	2/10/2017	79	354	11.27	
HS3		20	11/23/2016	2/10/2017	79	360	11.46	

The experimental assessment of the tensile properties of SFRC are difficult, and there is no standard test exists to determine the stress-strain curve of fiber reinforced concrete in direct tension [18]. This is because, the observed experimental curve depends on the size of the specimen, that need for specimens that have a large cross section such that a fiber distribution similar to that in real structural members. Therefore, direct tensile test results are usually significantly scattered and rare.
In this research work, the primary benefits of fiber addition to concrete which improve the tensile response after cracking and improve crack control, also showed that any addition of steel fiber to concrete improves the tensile toughness of concrete.

9. CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

1. The presence of steel fiber in a concrete matrix improve the toughness of SFC in compression, where toughness is a measure of ability to absorb energy during deformation, and it can be obtained from and this incensement in toughness is useful in preventing sudden failure under static loading.
2. Based on the results of these monotonic tests, one can observe that the increases in the compressive strength of concrete ranging from (48 -61%) for up to 1.0 percent by volume of fibers.
3. The primary benefits of steel fiber addition to concrete which improve the tensile response after cracking and improve crack control, also showed that any addition of steel fiber to concrete improves the tensile toughness of concrete.

4. The addition of the steel fiber results in the incensement of the tensile strength of concrete ranging from (58 -62%) for up to 1.0 percent by volume of fibers.

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